Satellite Observations, Surface Signature and Properties of Nonlinear Internal Waves

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LONG-TERM GOALS

The long term goal of this proposed project is to improve our understanding of the nonlinear internal waves, in particular what observations and measurements are needed to predict better existence and propagation of soliton packets as well as determine their strength (amplitude) and origin.

To improve our descriptions of nonlinear internal waves we propose a two-fold approach by acquiring satellite data such as SAR and medium resolution optical imagery and make measurements of surface and near-surface oceanic properties during the passage of internal wave soliton packets along the continental shelf.

OBJECTIVES

1) To determine the characteristics of nonlinear internal waves on the continental shelf with SAR imagery.
2) To map the occurrence and frequency of internal wave soliton packets in SAR imagery and trace their origins.
3) To determine the location and generation mechanism of nonlinear internal waves on the continental shelf.
4) To measure surface signatures and Bragg modulations during the passage of soliton packets.
5) To measure the strength, orientation and variability of the induced near surface flow during the passage of internal wave packets.
6) To measure the variability of near surface density during the passage of soliton packets.
7) To acquire additional observations of the environmental oceanic and atmospheric conditions that can be related to detection of solitons in SAR imagery.

APPROACH

During the Shallow Water 06 (SW06) experiment off the coast of New Jersey three sets of measurements will be collected for an eight week period. First, two air-sea interaction spar (ASIS) platforms were deployed at the center of the mooring array to provide local air-sea interaction observations. The measurements of surface and near-surface oceanic properties during the passage of

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IW solitons will include directional surface wave and near surface turbulence parameters. In particular, the ASIS buoys made direct measurements of directional spectra of surface gravity waves and estimates of the surface roughness that affect the scattering characteristics of sea surface. Simultaneously wind stress, atmospheric stability and near surface flow turbulence estimates will also be obtained to understand in which atmospheric windows and sea state conditions satellites and shipborne radars can observe the presence of internal waves (IWs). WOTAN sensors attached to the tether buoys will measure acoustically the intensity of ambient noise usually correlated with wave breaking and wind speed.

CSTARS will acquire an extensive set of synthetic aperture radar (SAR) and electro-optical (EO) images during the SW06 experiment. Images from satellite SARs such as RadarSat-1, ERS-2 and ENVISAT ASAR using different beam modes were scheduled for direct downlink to CSTARS that included also ScanSAR, standard and fine beam modes. We also acquired all images of MODIS on Aqua and Terra and submitted task order schedules for EO satellites SPOT 2 & 4. All images were made available in near real time (within <3 hours) and provided to ships and airborne operations to guide mobile and autonomous measurements of the IWs.

Two WaMoS marine X-band radar systems were installed on the *R/V Knorr* and *R/V Oceanus* for the duration of the SW06 experiment. The WaMoS systems were operated in short-pulse mode on the *R/V Knorr* to obtain unambiguous directional wave spectra and surface current information in real time by analyzing the temporal and spatial evolution of the radar backscatter from the sea surface, received in the near range of the radar (sea clutter). From this wave spectrum all important sea state parameters are derived. Also the radar images will delineate the presence of IWs in the IFOV. The WaMoS systems on the *R/V Oceanus* was operated in various modes, but primarily in medium-pulse to obtain better along crest coverage of IWs approaching the ship.

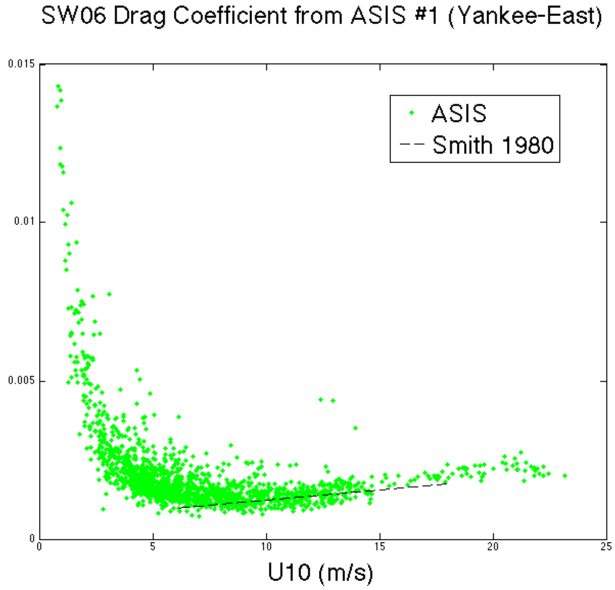
WORK COMPLETED

1) All satellite data have been processed and analyzed for internal waves.
2) All internal waves in the satellite images have been traced to allow better quantitative analysis and correlation with in-situ and shipborne measurements.
3) The ASIS buoys data have been processed and time series have been produced for most parameters.
4) The WaMoS marine X-band radar data on the *R/V Knorr* and *R/V Oceanus* have been processed and analysis is continuing. On the *R/V Knorr* the system was operating in short-pulse mode and in addition to internal wave parameters we are also extracting directional wave information, surface current fields and wind speed estimates. On the *R/V Oceanus* the system was operating in medium-pulse mode and we have produced long movie string of internal wave events and using this data with the satellite data analysis.
5) Two NLIWI specific websites, one password protected, and the other for public information, are established to post information of satellite collections and display images and annotated images with bathymetry and SW06 mooring locations. (https://charon.cstars.miami.edu/swarm).

RESULTS

Air-Sea Interaction Measurements:

The two ASIS buoys measured wind stress, atmospheric pressure, air temperature and relative humidity on the atmospheric side and water temperature as well as 3-dimensional currents at several depths on the ocean side and directional wave spectra for the entire SW06 experiment. The experimental period included the passage of Tropical Storm Ernesto to the west of the NLIWI site which increased winds and sea state to nearly 25 m/s and 7 m, respectively. Figure 1 (left panel) shows the neutral drag coefficient as a function of wind speed derived directly from sonic anemometer measurements using eddy-correlation technique. Superimposed is the Smith (1980) bulk relationship which does not capture adequately the drag conditions at both high and low winds. Figure 1 (right panel) shows an example of the directional wave spectrum during the approaches of TS Ernesto displaying multiple wave systems in the region.



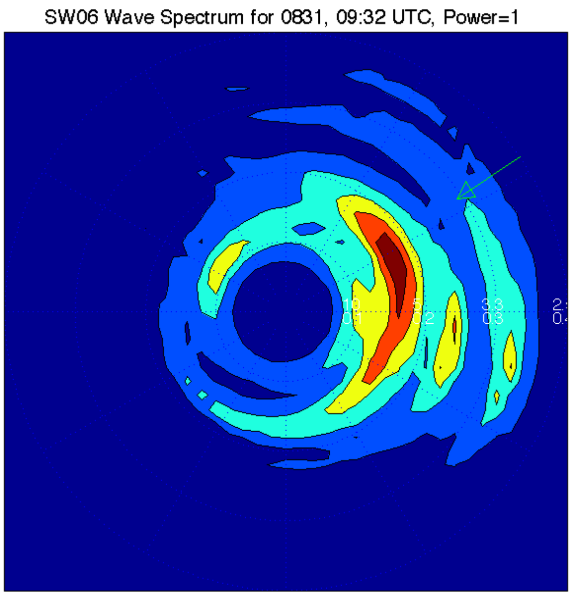


Figure 1: Left: Scatter plot of drag coefficient versus 10m height, neutral wind speed from the ASIS "Yankee" buoy during the NLIWI experiment. Right: A typical directional wave spectrum from the ASIS buoy during the approach of TS Ernesto over the NLIWI region.

On the tether buoys, a WOTAN sensor was deployed to measure acoustically the intensity of ambient noise which may change with the presence of IWs movement. The data for the WOTAN sensor have not yet been analyzed, but will provide another source of wind observations.

Satellite Imagery:

The analysis of the satellite data show several interesting results. Although the majority of packets were aligned with the local bathymetry, several packets were observed intersecting with each other. Figure 2 (left panel) shows the intersection of packets 05 and 09 from the ERS2 pass on August 8, 2006. The resulting intersection angle is 41.15°. Figure 2 (right panel) shows a SPOT image from August 17, 2006 with multiple internal wave packets, the locations of surface and subsurface moorings and the ship track of the *R/V Oceanus*.

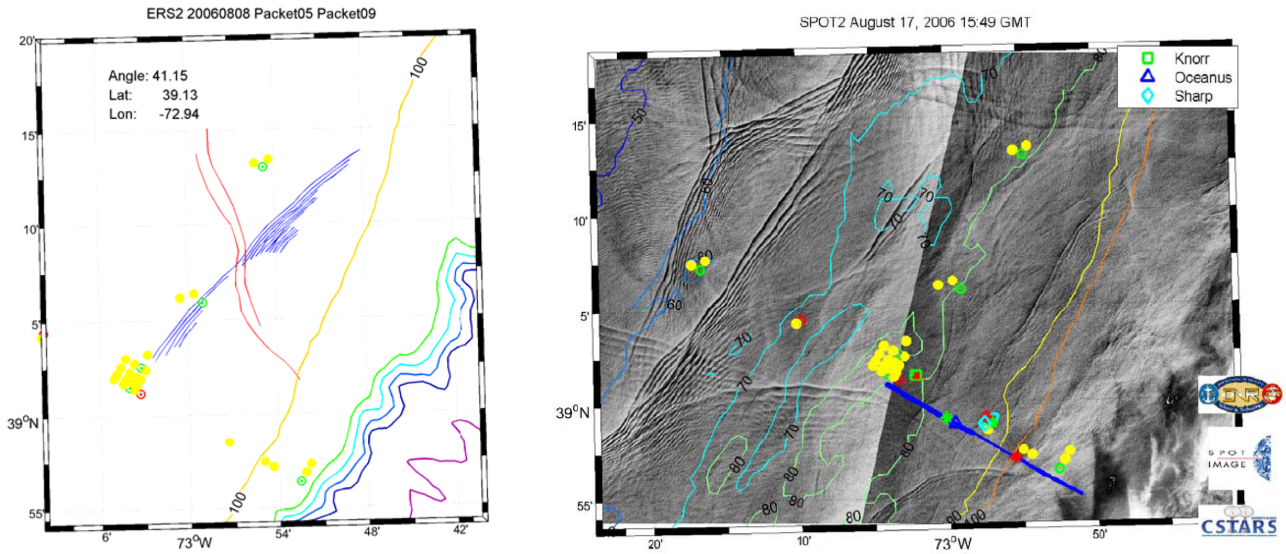


Figure 2: Left: Map displaying two intersecting internal wave trains captured by an ERS-2 SAR image on 8 August 2006. Right: An optical SPOT image displays multiple wave trains of internal waves in the vicinity of the NLIWI mooring array. The R/V Oceanus ship track is also shown which followed the inshore propagation of one such IW packet.

Table 1 provides a summary of how many IW packets were imaged and the number of internal waves present. Table 2 summarizes the mean parameters of the IWs observed during the NLIWI experiment.

- ***SW06 - 472 packets composed of 2901 internal waves***
  - Radarsat – 193 packets; 993 internal waves
  - Envisat/ERS2 – 46 packets; 308 internal waves
  - Spot 2 – 118 packets; 854 internal waves
  - Spot 5 – 115 packets; 746 internal waves

Table 1: Summary of IW packets and solitons observed by satellites during the NLIWI experiment.

Wave speed	0.8 – 1.1 m/s
Wave length	0.3 – 0.7 km
Packet length	2 – 10 km
Along wave length	20 – 50 km
Packet separation	7 – 30 km

Table 2: Summary of mean characteristics of internal waves derived from optical and microwave SAR satellite imagery.

Marine X-Band Radar:
Two WaMoS marine X-band radar systems were installed on the *R/V Knorr* and *R/V Oceanus* for the duration of the SW06 experiment. The *R/V Knorr* utilizes a Furuno FR-2827 radar antenna operating at 24 rpm. The WaMoS system was placed in short pulse mode and recorded a radar image every revolution which corresponds to 2.5 seconds. Figure 3 shows time series comparisons of significant wave from the WaMoS system using two algorithms with different noise characterizations and the ASIS buoy. This segment show wave height conditions during the passage of Tropical Storm Ernesto when waves exceeded 7.5 m in the NLIWI experimental region.

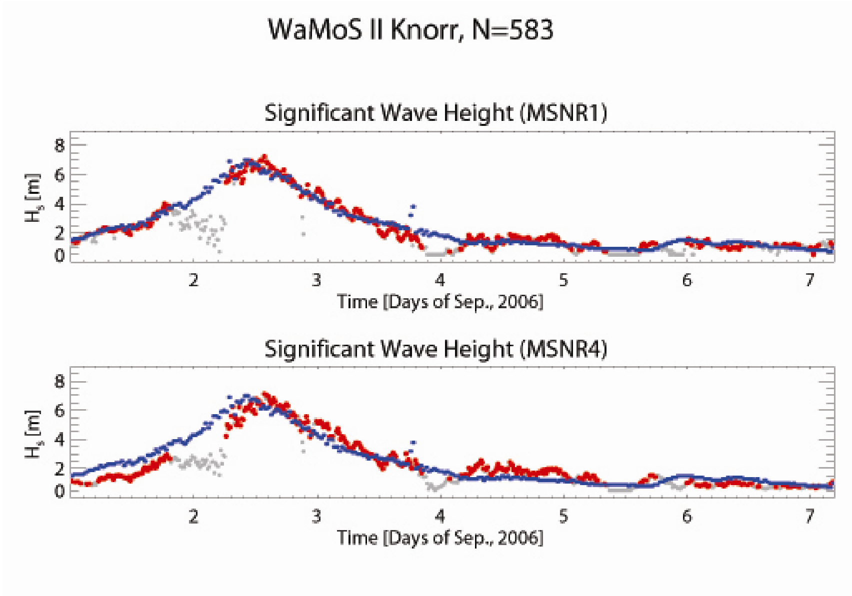


Figure 3: WaMoS radar time series measurements of significant wave height from the R/V Knorr using two different noise characterizations. The radar measurements (red) are compared to ASIS buoy wave heights (blue).

IMPACT/APPLICATIONS
Improved multiple datasets measured simultaneously and coincident of internal waves will permit to predict when internal wave trains are generated given the local oceanic state.

TRANSITIONS
None.

RELATED PROJECTS
Remote sensing observations were made during a complementary experiment in the Luzon Straits and Philippine Sea.